# *Refurbishing an existing apartment block in Mediterranean climate: towards the Passivhaus standard*

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 00 (2016) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

8th International Conference on Sustainability in Energy and Buildings, SEB-16, 11-13 September 2016, Turin, ITALY

# Refurbishing an existing apartment block in Mediterranean climate: towards the Passivhaus standard

Agata Consoli[a], Vincenzo Costanzo[b], Gianpiero Evola[a*], Luigi Marletta[a]

[a] Dipartimento di Ingegneria Elettrica, Elettronica ed Informatica, University of Catania, Viale A. Doria 6, 95125 Catania, Italy
[b] School of Construction Management and Engineering, University of Reading, Whiteknights, PO Box 219, Reading, Berkshire, UK

**Abstract**

The Passivhaus standard, although widely appreciated in cold regions, is seldom regarded as a reference in the energy renovation of existing buildings in warm countries. This paper evaluates the effectiveness of a series of strategies for the energy refurbishment of an existing apartment block in Southern Italy, based on dynamic energy simulations. The paper aims to show that, in warm Mediterranean areas, a building refurbishment must not be oriented towards an excessive insulation level. Conversely, if aimed to comply with the Passivhaus standard, the renovation must look above all at those strategies that mitigate the energy needs for space cooling and improve thermal comfort in summer.


*Keywords:* Refurbishment; Apartment block; Mediterranean climate; Passivhaus; Thermal comfort

## 1. Introduction

Since its origin in the late 1980's, the application of the Passivhaus standard [1] has focused on new constructions located in cold climates, such as those of Central and Northern Europe. As a consequence, the key concepts of this standard were the envelope superinsulation, the airtightness and the use of ventilation systems with performing heat recovery. The standard requires to achieve energy needs for space heating lower than 15 kWh $m^{-2}$ $y^{-1}$, and total primary energy needs (heating, domestic hot water and electrical appliances) below 120 kWh $m^{-2}$ $y^{-1}$. All the surface-averaged energy figures refer to the net liveable area. Moreover, air infiltrations must be less than 0.6 $h^{-1}$ at a

* Corresponding author. Tel.: +39-95-7382421; fax: +39-95-7382496.
*E-mail address:* gevola@unict.it

1876-6102 

pressure difference of 50 Pa. So far, the application of this standard proved to be so successful in achieving the proposed goals, as to give raise to the *Zero Energy Building* concept, introduced in the EU Directive 2010/31 [2] and implemented in several new buildings within the EU countries [3]. However, its dissemination overseas and for warm climates proved to be questionable, and thus still deserves accurate research. To this aim, the Passive-On project resulted in the publication of guidelines for designing Passive Houses in Southern Europe [4]. In this context, a further limitation is introduced, i.e. to keep the sensible energy demand for space cooling below 15 kWh $m^{-2}$ $y^{-1}$. Furthermore, space cooling has to be included in the calculation of the total primary energy needs, and a lower air tightness is allowed (1 $h^{-1}$ at 50 Pa) if the ambient temperature does not drop below 0°C.

Within this research stream, some authors studied how to cope with potential overheating issues and increased cooling energy needs for mild-to-warm climates. As an example, Figueiredo et al. [5] carried out an extensive simulation study for optimizing the design of new buildings in terms of both thermal comfort and energy needs based on an existing well-performing detached house in Portugal. Sameni et al. [6] and Sassi [7] investigated overheating problems in existing UK flats designed to accomplish Passive House standards, finding that it is possible to achieve Passive House goals just by naturally ventilating the building.

Badescu et al. [8] assessed the feasibility of Passive Houses in Southern Hemisphere countries located at reversed latitudes and with similar climatic conditions of typical EU countries, by adapting the construction details of a prototype passive building built in Romania. Again, they found out that the thickness of thermal insulation may be decreased in warm climates like in South America and New Zealand, thus allowing for capital cost savings and construction simplifications. On the other hand, Schnieders et al. [9] simulated the performance of a reference two-floor detached house built in Hannover in very different climates, from the very cold city of Yekaterinburg in Russia to the hot-humid city of Abu Dhabi in the Emirates. This work is worth of attention because it highlights that specific construction details are needed to meet the Passivhaus requirements, even if in Abu Dhabi it is not possible to keep the sensible energy demand for space cooling below 15 kWh $m^{-2}$ $y^{-1}$. Finally, Attia and Zawaydeh [10] investigated on passive and active design strategies for an existing apartment in Jordan, with the aim of reaching a zero energy retrofit. Their results showed that the NZEB objective is too ambitious, having a 30-year payback time.

A step forward in this sense is made in this paper, where an existing multi-storey apartment block, located in the Mediterranean climate of Catania, is modelled in EnergyPlus. The aim is to provide suggestions about possible refurbishing options to comply with the extended Passivhaus requirements for Southern Europe.

**Nomenclature**

| | |
|---|---|
| A | net surface of the building ($m^2$) |
| COP | Coefficient of Performance (-) |
| E | electric energy need (kWh $year^{-1}$) |
| EER | Energy Efficiency Ratio (-) |
| ITD | Intensity of Thermal Discomfort (°C h) |
| n | air change rate for natural ventilation or infiltration ($h^{-1}$) |
| Q | thermal energy need (kWh $year^{-1}$) |
| PE | primary energy need (kWh $m^{-2}$ $year^{-1}$) |
| PER | primary energy ratio (-) |
| r | solar reflectance (-) |
| $T_{op}$ | operative temperature (°C) |
| U | thermal transmittance (W $m^{-2}$ $K^{-1}$) |

## 2. Methodology

### *2.1. Calculation of final and primary energy needs*

As highlighted in the previous section, one of the requisites for a building to comply with the Passivhaus standard is that its overall primary energy consumption does not exceed 120 kWh/year per unit useful surface. The overall primary energy consumption should take into account all energy-consuming services, namely space heating (H), space cooling (C), domestic hot water production (W), artificial lighting and other electrical appliances (EL).

In order to check this condition, in this paper the overall primary energy consumption is assessed through Eq. (1):

$$PE = \left( \frac{Q_H}{PER_H} + \frac{Q_C}{PER_C} + \frac{Q_W}{PER_W} + \frac{E_{EL}}{\eta_{EL}} \right) \cdot \frac{1}{A_b} \tag{1}$$

Here, the thermal energy needs for space heating ($Q_H$) and space cooling ($Q_C$) are evaluated by means of dynamic thermal simulations performed through the software tool Energy Plus. In the dynamic simulations, the thermostat control for indoor air temperature is set respectively at 20°C in winter and at 26°C in summer, from 14:00 to 22:00. Further details about the model of the building for the dynamic thermal simulations are provided in Section 3.1.

On the other hand, the thermal energy needed for domestic hot water production ($Q_W$) is calculated by Eq. (2):

$$Q_W = m_w \cdot C_{pw} \cdot (T_w - T_n) \tag{2}$$

Here, $m_w$ = 40 kg/day per person is the average need of hot water in residential buildings, whereas $T_w$ = 40°C and $T_n$ = 15°C are respectively the temperature of the hot water provided to the users and the temperature in the cold water main.

The electricity consumption for artificial lighting and other electrical appliances are detailed in Section 3.1. In Eq. (1) it is also necessary to assess the Primary Energy Ratios (PER). They depend on the technology adopted to produce or extract thermal energy. As a rule, the PER of a gas-fired heat generator corresponds to its conversion efficiency. On the other hand, in electricity-driven reversible heat pumps the PER can be calculated by multiplying the average Coefficient of Performance (COP in winter and EER in summer) by the average efficiency for electricity production and distribution. In Europe, this can be currently set as $\eta_{el}$ = 0.46.

### *2.2. Evaluation of summer thermal comfort*

The occurrence of thermal discomfort due to overheating in a living space is usually assessed by measuring how frequently the *room operative temperature* exceeds a threshold value. However, in the authors' opinion such information is only partial, since one should account for both the duration and the intensity of thermal discomfort.

On this basis, the authors propose to use an indicator called *Intensity of Thermal Discomfort* (ITD), already introduced in a previous work [11]. This indicator is defined as the time integral, over the occupancy period P, of the positive difference between the current indoor operative temperature and the upper threshold for comfort (see Eq. 3).

$$ITD = \int_P \left( T_{op}(\tau) - T_{lim} \right)^+ d\tau \tag{3}$$

In residential buildings, the occupancy period P corresponds to 24 hours per day. As the ITD gets higher, the discomfort for overheating gets more important; furthermore, a same value of the ITD obtained by means of two different building solutions means that they allow the achievement of the same average thermal comfort, in terms of duration and intensity, over the whole period of integration

As concerns the choice of the threshold temperature $T_{lim}$, this depends on the thermal comfort theory that is adopted. In this work, the authors refer to the *adaptive theory*, which is most suitable to assess thermal comfort in free-running conditions, as described in EN 15251 [12]. In this case, the threshold value is not constant in time, but it should be updated daily as a function of the running mean outdoor air temperature $T_{rm}$. The formulation of the threshold temperature is given in Eq. (4); this corresponds to the fulfilment of Category I introduced by the EN Standard (high level of expectation).

$$T_{lim} = 20.8 + 0.33 \cdot T_{rm} \tag{4}$$

## 3. Case study

### *3.1. Description of the building*

The building investigated in this paper is a multi-storey apartment block, situated in the city centre of Catania, a town on the Eastern coast of Sicily, in Southern Italy. Here, the climate is warm in winter, as witnessed by the low Heating Degree Days (HDD = 833 °C day), defined relative to a base outdoor temperature of 12°C. According to Italian regulations, Catania belongs to the climatic zone B, and the operation of the space heating systems is allowed eight hours per day, from the 1st of December to the 31th of March. On the other hand, in summer the climate is relatively hot and humid, with peak outdoor temperatures that may frequently exceed 35°C. The average daily profiles for the main climatic data in Catania are shown in Fig. 1.a.

The apartments are distributed over seven floors. The ground floor hosts five apartments, whereas all other floors contain six apartments. Overall, the building hosts 41 apartments, with an average useful surface of 111.8 m$^2$ per apartment. The building is C-shaped, with the long side and the short side measuring respectively 47.5 m and 20.9 m The main façade is oriented due South-West. However, other tall buildings surround the apartment block; hence, the outside walls do not receive much direct solar radiation, irrespective of the orientation. In the simulations, all neighbouring buildings have been properly modelled, as shown in Fig. 1.b. Here, it is possible to observe that in the simulations only one of the intermediate floors is modelled, that is representative of all other ones; all intermediate horizontal slabs are held adiabatic. Other information about the apartment block is reported in Table 1.

The proposed building has a reinforced concrete structure, which is very widespread in Mediterranean countries and especially in Italy. The outside walls are based on a double-leaf construction, with two layers of common hollow clay bricks, whose thickness is 120 mm on the outer side and 80 mm on the inner side, respectively. The two leaves are divided by a 100-mm cavity without insulation. The overall thickness, including inner and outer plaster, is 340 mm. The outer plaster has a relatively clear colour; in the simulations, a solar reflectance $r = 0.6$ is retained.

As regards the flat roof, it consists of a 200-mm slab, made of reinforced concrete and hollow bricks, overlaid by two layers of concrete screed to fall (40 mm plus 40 mm), that are separated by a 0.3-mm polythene vapour barrier. The roof is completed by cotto tiles (10 mm), whose solar reflectance is $r = 0.3$.

Table 1. General information about the building

| | |
|---|---|
| Location | Catania, Italy (Lat. 37°31' N, Long. 15°04' E) |
| Number of floors | 7 |
| Number of flats | 41 |
| Main façade | South-west |
| Overall net surface | 4582.6 m$^2$ (111.7 m$^2$/apartment) |
| Opaque envelope surface | 4757.6 m$^2$ |
| Transparent envelope surface | 545.3 m$^2$ |
| Net volume | 13837.3 m$^3$ |

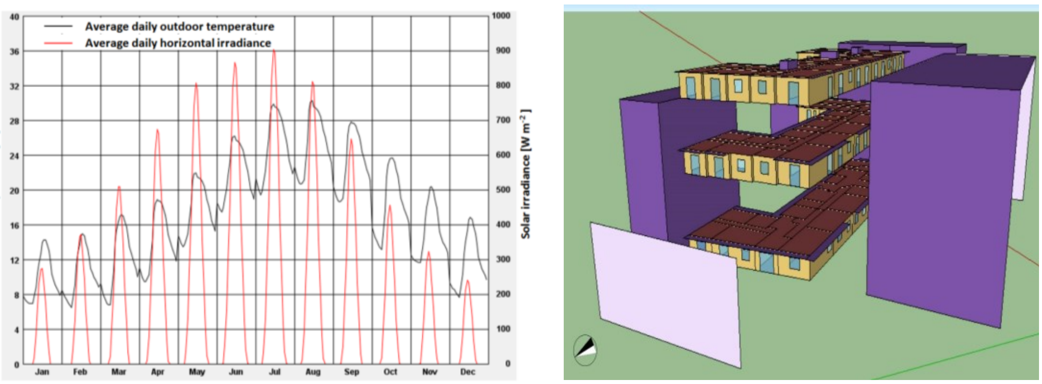


Fig. 1. (a) Average climatic data in Catania – daily profiles, (b) model of the multi-storey apartment block on EnergyPlus.

A similar stratigraphy, but just with only 40 mm of screed to fall, pertains to the slab separating the ground floor from the underfloor parking area. The windows are provided with aluminium profiles without thermal-break, and a single 3-mm glazing with standard thermal emissivity ($\varepsilon = 0.84$). The thermal transmittance of the main envelope components is reported in Table 2, which also shows the maximum values allowed from 2021 in Italy in case of energy refurbishment of an existing building; these values refer to the climatic zone B. Table 2 also reports the thermal mass and the heat capacity of the opaque envelope components.

Table 2. Properties of the main envelope components

| | U | U limit (2021) | Thermal mass | Heat capacity |
|---|---|---|---|---|
| Outside walls | 1.1 W m$^{-2}$ K$^{-1}$ | 0.40 W m$^{-2}$ K$^{-1}$ | 210 kg m$^{-2}$ | 190 kJ m$^{-2}$ K$^{-1}$ |
| Flat roof | 2.3 W m$^{-2}$ K$^{-1}$ | 0.32 W m$^{-2}$ K$^{-1}$ | 650 kg m$^{-2}$ | 600 kJ m$^{-2}$ K$^{-1}$ |
| Slab above the underfloor parking area | 2.4 W m$^{-2}$ K$^{-1}$ | 0.42 W m$^{-2}$ K$^{-1}$ | 570 kg m$^{-2}$ | 515 kJ m$^{-2}$ K$^{-1}$ |
| Windows (average) | 5.9 W m$^{-2}$ K$^{-1}$ | 3.00 W m$^{-2}$ K$^{-1}$ | not relevant | |

All windows have no movable shading devices; indeed, the solar irradiance available on the façade is already low, due to the shading effect of the surrounding buildings and of the balconies. Further shadings would imply an excessive reduction in the daylight availability.

As concerns natural ventilation, a constant rate is considered in the simulations. In particular, $n = 0.5$ h$^{-1}$ in summer and $n = 0.3$ h$^{-1}$ in winter [13], as also suggested by national standards [14]. Such values include air infiltration; in fact, the air-tightness of the envelope is not easy to know, if not through a blower door test. However, the wind pressure on the envelope is strongly reduced by the surrounding buildings; hence, the effect of infiltration is likely to be negligible in this case. The simulations take into account the internal loads due to people, artificial lighting and electrical appliances. In particular, each apartment hosts four people, performing sedentary activities (60 W sensible load). The peak electric power of the lamps is 7 W/m$^2$. As regards the electrical appliances, the following peak values are retained: 200 W for computers and TV set, 1300 W for kitchen appliances and 1500 W for other appliances. These values correspond to energy efficiency class C according to the labelling scheme introduced by EU [15], and have been gathered from a survey carried out by ENEA research institute [16]. Of course, suitable occupancy schedules and usage patterns have been introduced, with a peak occupancy occurring from 23:00 to 07:00, and no people inside the dwellings from 16:00 to 19:00. Overall, the electricity consumption for lighting and appliances is 31.8 kWh/m$^2$ per year, which is used in Eq. (1) to calculate the primary energy needs.

Finally, space heating is provided by individual gas-fired heat generators. The overall efficiency of the space heating system, including the losses due to heat distribution and emission, is $\eta_H = 0.8$. On the other hand, space cooling is performed through individual split units, with an average EER = 2.5. The efficiency of the gas-fired systems for domestic hot water production is $\eta_W = 0.7$. No mechanical ventilation system is installed.

### *3.2. Proposed strategies for energy efficiency*

After assessing the energy performance and the summer thermal comfort for the building in its current configuration, an additional series of dynamic simulations is performed to identify the most suitable strategies that may approach the Passivhaus requisites in case of energy refurbishment.

First of all, the thermal transmittance of all the outside envelope components is reduced below the limits imposed by national regulations for energy refurbishment, see Table 2. To this aim, a layer of insulating material is applied to the outer side of the walls and under the screed to fall in all slabs. In particular, cork has been chosen as the insulating material, since it is biocompatible, highly breathable and fully recyclable if not treated with chemical agents. The thickness of the cork boards needed to comply with the regulations is reported in Table 3.

Table 3. Thickness of the insulation and new thermal transmittance (step 1)

| | Cork thickness (mm) | U (W m$^{-2}$ K$^{-1}$) |
|---|---|---|
| Outside walls | 80 | 0.35 |
| Flat roof | 120 | 0.30 |
| Slab above the underfloor parking area | 90 | 0.39 |

In the same time, all existing windows are replaced by double 6-mm sealed glazing filled with argon, with PVC frame; the resulting average thermal transmittance is U = 2.9 W $m^{-2}$ $K^{-1}$.

The proposed energy refurbishment also involves the adoption of rather efficient energy systems. Hence, space heating and space cooling are thought to be performed by means of a centralized high-efficiency electricity-driven reversible heat pump, with COP = 3.65 in winter and EER = 3.25 in summer. Such values correspond to the average performance figures of a real unit, as declared by a well-known manufacturer, and take into account the dependence of the performance on the outdoor dry bulb temperature. The results of the simulations for the proposed solution of refurbishment are reported in Section 4.1, where they are identified by the label “step 1”.

However, natural ventilation may have a crucial role for improving the building energy performance in summer, especially if exploited during nighttime. For this reason, further simulations were carried out by varying the rate of natural ventilation up to $n = 2$ $h^{-1}$ in summer, i.e. from June to September, but only from 21:00 to 07:00. The results of this analysis are shown in Section 4.2. Finally, based on the results of the first series of simulations, a final solution for refurbishment is considered. This step aims at investigating whether it is still possible to comply with the Passivhaus standard by lowering the level of insulation of the envelope compared with national regulations, while also introducing other low-cost passive solutions to improve summer performance, such as cool coatings and reflective glazing. The results of this investigation are described in Section 4.3.

## 4. Results and discussion

### *4.1. Comparison between the current building and the first solution for refurbishment*

The results of the dynamic simulations in terms of final energy needs for space heating and space cooling are shown in Fig. 2. When looking at the building in its current state (Fig. 2.a), one can observe that the top floor is by far characterized by the highest energy needs, because of the large surface of the roof exposed to the outdoors. In summer, this horizontal surface is hit by high solar irradiance, which determines a cooling energy demand more than twice as high as for the intermediate floors. On the other hand, in summer the ground floor takes advantage of the heat exchange with the underfloor parking area, which is cooler than the outdoor air, and not hit by solar radiation. Consequently, its energy demand for space cooling is around 60% lower than for intermediate floors. However, on average the building does not respect the threshold (15 kWh $m^{-2}$ $y^{-1}$), neither in the cooling nor in the heating season.

The solution of refurbishment based on the envelope insulation, up to the limits imposed by national regulations, is not entirely satisfying. In fact, on the one hand the energy needs for space heating are drastically reduced in all floors; on average, for the whole building they are cut down from 17.5 kWh $m^{-2}$ $y^{-1}$ to 5.1 kWh $m^{-2}$ $y^{-1}$, that is to say by around 71% (Fig. 2.b). Hence, this solution of refurbishment would imply the compliance with the requisite of the Passivhaus standard, at least for space heating. But on the other hand, the insulation of the envelope prevents heat from being effectively dissipated outdoors in summer, especially at night; thus, the energy needs for space cooling increase by 13% in the intermediate floors and by 2% for the entire building, if compared to the current situation. The only exception is the top floor, where a good insulation effectively counteracts the overheating of the horizontal roofs; here, the proposed refurbishment yields a reduction by 33% in the space cooling needs.

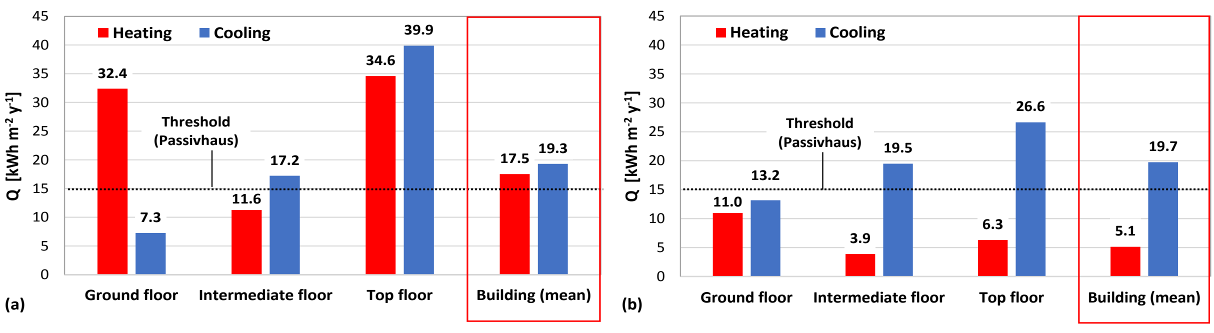


Fig. 2. Energy needs for space heating and space cooling. (a) Existing building, (b) After refurbishment (step 1).

As a result, the final average cooling energy demand (19.7 kWh $m^{-2}$ $y^{-1}$) is slightly higher than for the building in its current state (19.3 kWh $m^{-2}$ $y^{-1}$), and this does not allow the compliance with the Passivhaus standard.

Moreover, Fig. 3 reports the results in terms of primary energy demand, calculated through Eq. (1). Here, one can observe that the highest contribution comes from artificial lighting and electrical appliances (from 67 to 70 kWh $m^{-2}$ $y^{-1}$). The intermediate floors show an overall primary energy demand PE slightly lower than the threshold value (120 kWh $m^{-2}$ $y^{-1}$), but on average PE = 130.5 kWh $m^{-2}$ $y^{-1}$ for the whole building (Fig. 3.a).

On the other hand, the solution of refurbishment does not modify the primary energy demand for artificial lighting, electrical appliances and hot domestic water, but it allows a consistent reduction in the primary energy needs for space heating and cooling. In this sense, an essential contribution also comes from the adoption of high-efficiency reversible heat pumps. In all floors the threshold set by the Passivhaus standard is met (Fig. 3.b); on average, PE = 107.5 kWh $m^{-2}$ $y^{-1}$ for the building.

Finally, Fig. 4 shows the results of the simulations in terms of Intensity of Thermal Discomfort. Here, the range of the ITD values has been arbitrarily split into five intervals, ranging from green to red according to the increasing degree of summer discomfort. What is interesting to underline is that, after refurbishment, the building would show, for all thermal zones, higher ITD values than in its current configuration. As explained in Section 2.2, this means that the discomfort for overheating would increase after the proposed refurbishment. This confirms that the envelope insulation, even if limited to the level imposed by national regulations, may have negative effects in summer, both in terms of energy needs and – above all – in terms of thermal comfort for the occupants.

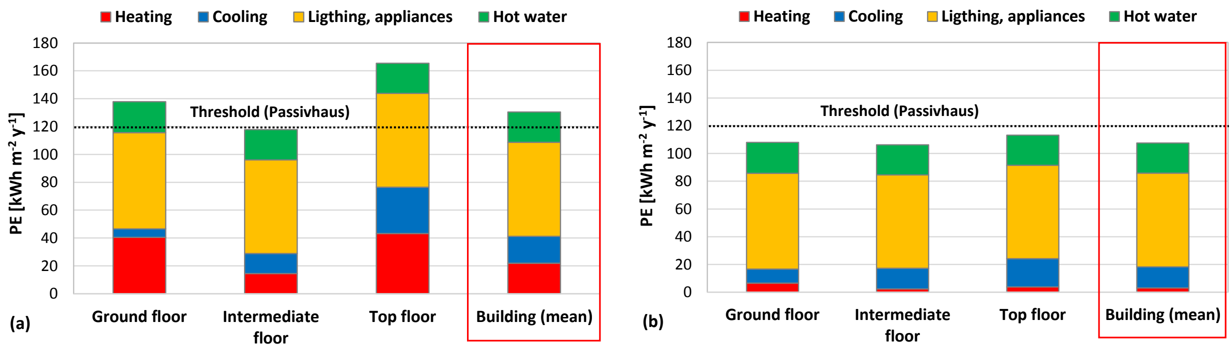


Fig. 3. Overall Primary Energy consumption. (a) Existing building, (b) After refurbishment (step 1).

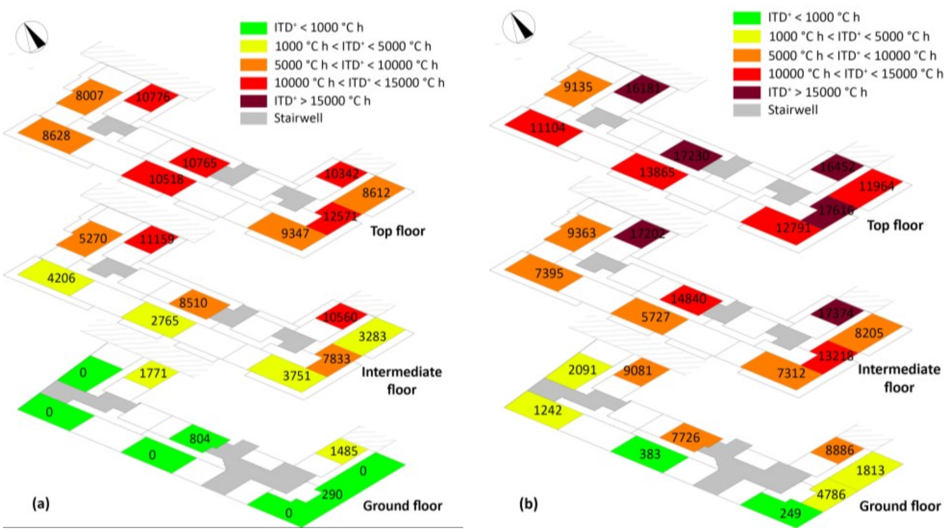


Fig. 4. Intensity of Thermal Discomfort for summer overheating. (a) Existing building, (b) After refurbishment (step 1).

### *4.2. The role of natural ventilation in summer*

Natural ventilation at night is usually regarded as an effective solution to improve the energy performance of buildings in summer, especially in hot climates. Hence, this section is devoted to investigate the sensitivity of the energy needs for space cooling to the rate of natural ventilation. To this aim, starting from the configuration of the building after refurbishment, the simulations are repeated by allowing a variation of $n$ from 0.5 $h^{-1}$ to 2 $h^{-1}$, just in the period between 21.00 and 07:00. During the rest of the day, the rate of ventilation is set as $n$ = 0.5 $h^{-1}$.

The results, reported in Fig. 5, show that doubling the rate of natural ventilation at night from $n$ = 0.5 $h^{-1}$ to $n$ = 1 $h^{-1}$ yields a 10% reduction in the cooling energy needs. A further 20% can be saved when moving from $n$ = 1 $h^{-1}$ to $n$ = 2 $h^{-1}$. In this case, the average energy needs of the entire building fall below the threshold of 15 kWh $m^{-2}$ $y^{-1}$, but this is not true for just the top floor.

However, in the authors' opinion $n$ = 2 $h^{-1}$ is not realistic in natural ventilation, especially for a building located in the city center and surrounded by other tall buildings. Such a high ventilation rate might be obtained only by opening all windows in the dwelling, which may cause noise and loss of privacy. For this reason, in the following $n$ = 1 $h^{-1}$ is kept, which is a reasonable value. In the next section, further strategies to approach the requisites of the Passivhaus standard will be investigated.

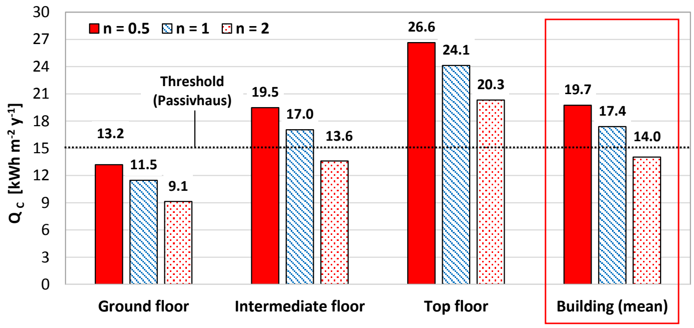


Fig. 5. Sensitivity of the energy needs for space cooling to the natural ventilation rate

### *4.3. Optimizing the solution of refurbishment - towards the Passivhaus standard*

From the results discussed so far, it is possible to state that increasing the envelope insulation does not necessarily imply the compliance with the Passivhaus standard. In this section, a further solution for refurbishment is considered. Here, the level of envelope insulation is slightly loosened, but other passive solutions are introduced. In particular, the proposed strategies consist in:

- Reducing the thickness of insulation in the bottom slab from 90 mm to 70 mm;
- Reducing the thickness of insulation in the outside walls from 80 mm to 50 mm, except in the ground floor and in the top floor, that already show sufficiently low energy needs for space cooling;
- Providing the windows with reflective outer glazing, which reduces by 45% the solar transmittance if compared with common double glazing; this strategy is not applied to the ground floor and to all windows exposed to north, that receive only diffuse solar radiation;
- Treating the outer surface of the roof and of the outside walls with a solar reflective paint ($r$ = 0.70). This performance level can be reached with water-based coatings containing fluoropolymer resins; a light colour must be selected, such as cream, ivory or light green [17, 18].

The results of the simulations for this set of strategies are discussed in the following.

First of all, by comparison of Fig. 6.a and Fig. 2.b, one can state that the strategies mentioned above produce a considerable increase in the heating energy needs for all floors; at a building level, such increase is around 30% (from 5.1 kWh $m^{-2}$ $y^{-1}$ to 6.9 kWh $m^{-2}$ $y^{-1}$). However, the energy needs for space heating were already much lower than the threshold, then this negative outcome is not crucial if aiming at the Passivhaus standard.

On the contrary, the proposed strategies drastically cut the energy needs for space cooling. In relation to the entire building, they fall from 19.3 kWh $m^{-2}$ $y^{-1}$ to 13.6 kWh $m^{-2}$ $y^{-1}$, which is to say by around 30%. Indeed, the slightly lower insulation level helps the building to reject heat, while all the other strategies described above are helpful to reduce the solar gains through the envelope. Now, both the energy needs for space heating and for space cooling keep below 15 kWh/$m^2$ per year. Moreover, in terms of primary energy demand the situation has also slightly improved with respect to Fig. 3.b. In relation to the entire building, it is around 3% less than before.

Finally, the proposed strategies determine a substantial improvement in the thermal comfort perceived in summer by the occupants. Indeed, the ITD values shown in Fig. 7.a are far lower than what observed in Fig. 4.b for the basic refurbishment strategy. As an example, in the apartment placed at the center of the intermediate floor (main façade) the ITD has decreased from 5727 (Fig. 4.b) to 1268 (Fig. 7.a). Based on the definition provided in Section 2.2, this 77% reduction means that people would suffer from a less intensive overheating, and a for a shorter time.

The overall comparison amongst the three building configurations is reported in Fig. 7.b. Here, each floor is described by the mean of the ITD values pertaining to all apartments. It is interesting to observe that the use of a cool paint for the roof has remarkable positive effects on the thermal comfort perceived at the top floor, where the average ITD decreases by 70% if compared to the basic refurbishment. However, a moderately intense thermal discomfort still occurs, since ITD >> 0. Hence, the use of the air-conditioning system is still required.

On the other hand, in the ground floor the ITD is very low and close to zero in most of the apartments, which means that thermal discomfort occurs seldom and, in any case, with very low overheating.

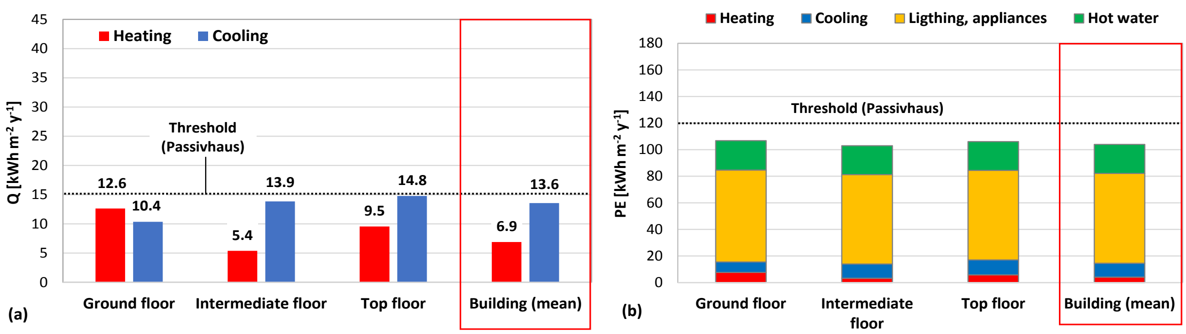


Fig. 6. Performance of the building in the final configuration. (a) Energy needs, (b) Primary energy consumption

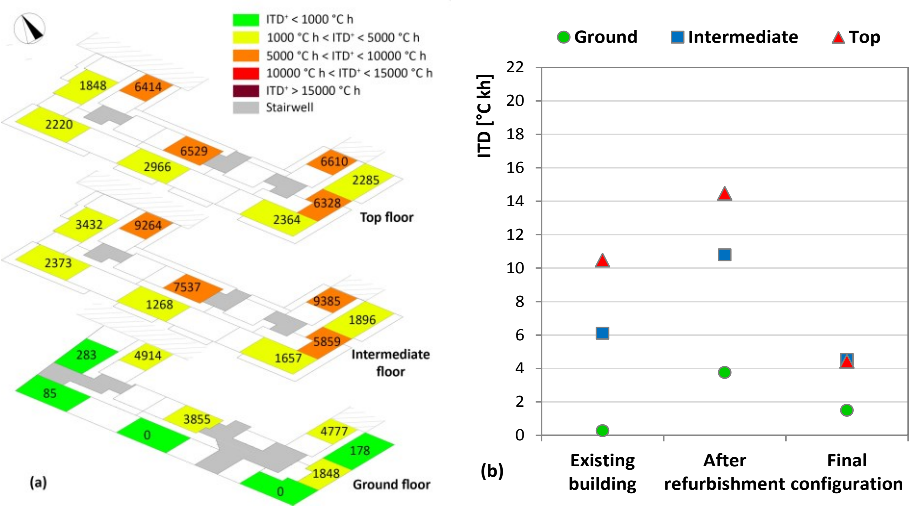


Fig. 7. (a) ITD for summer overheating: final solution, (b) Comparison between average values

## 5. Conclusions

The results presented in this paper suggest that refurbishing an existing apartment block in the city centre of a Mediterranean country, under the constraint of the Passivhaus standard, is nowadays an achievable task. However, to this aim a different strategy must be followed if compared to cold climates. In fact, in warm Mediterranean climates it is neither necessary to adopt mechanical ventilation systems with high-efficiency heat recovery, nor to provide excessive insulation to the envelope. Indeed, even a level of insulation corresponding to what prescribed by national regulations on energy savings might lead to overheating and significant thermal discomfort in summer.

On the contrary, in warm climates one should loosen the level of insulation, in order to facilitate heat dissipation in summer, while also accepting a moderate increase in the energy needs for space heating in winter. As an example, for the building considered in this paper the insulation of the bottom slab and the outside walls (with the exception of the ground floor and the top floor) has been reduced by 20 mm and 30 mm, respectively, if compared to the thickness needed to comply with national regulations. Moreover, all strategies aimed at passively cooling the building must be followed, such as an increased natural ventilation rate at night, the use of highly reflective outer glazing and the adoption of cool colours for the outer envelope. An adequate tuning of the performance parameters (air changes per hour, solar reflectance) has allowed the achievement of a final energy demand for heating and cooling lower than 15 kWh $m^{-2}$ $y^{-1}$, as suggested by the Passivhaus standard in its formulation for warm climates.

Finally, in order to meet the criterion that sets a limit to 120 kWh $m^{-2}$ $y^{-1}$ for the primary energy consumption, the adoption of high-efficiency reversible heat pumps is suggested (COP = 3.65 in winter and EER = 3.25 in summer). However, the calculations took into account the use of electrical appliances belonging to the energy efficiency class C, according to the labelling introduced by EU. In case of more efficient appliances, which is nowadays achievable, one might accomplish further energy savings, provided that the same level of comfort is assured to the occupants.

## References

[1] http://passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm. Retrieved on 04/04/2016
[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.
[3] http://www.passivhausprojekte.de/index.php?lang=en. Retrieved on 04/04/2016
[4] Ford B, Schiano-Phan R, Zhong D. The Passivhaus Standard in European warm climates: design guidelines for comfortable low energy homes. School of the Built Environment, University of Nottingham; 2007.
[5] Figueiredo A, Kämpf J, Vicente R. Passive house optimization for Portugal: Overheating evaluation and energy performance. Energ Build 2016;118:181-196.
[6] Tabatabaei Sameni SM, Gaterell M, Montazami A, Ahmed A. Overheating investigation in UK social housing flats built to the Passivhaus standard, Build Environ 2015; 92:222-235.
[7] Sassi P. A natural ventilation alternative to the Passivhaus standard for a mild maritime climate. Buildings 2013; 3:61-78.
[8] Badescu V, Rotar N, Udrea I. Considerations concerning the feasibility of the German Passivhaus concept in Southern Hemisphere. Energ Effic 2015; 8:919-949.
[9] Schnieders J, Feist W, Rongen L. Passive Houses for different climate zones. Energ Buildings 2015; 105:71-87.
[10] Attia S, Zawaydeh S. Strategic Decision Making For Zero Energy Buildings in Jordan. Proceedings of the ASHRAE Conference on Energy and Indoor Environment for Hot Climates, February 24-26 2014, Doha, Qatar.
[11] Sicurella F, Evola G, Wurtz E. A statistical approach for the evaluation of thermal and visual comfort in free-running buildings. Energ Build 2012;47:402-410.
[12] EN 15251. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics; 2007.
[13] ANSI/ASHRAE Standard 55-2013. Thermal Environmental Conditions for Human Occupancy; 2013.
[14] Evola G, Margani G, Marletta L. Cost-effective design solutions for low-rise residential Net ZEBs in Mediterranean climate. Energ Build 2014;68:7-18.
[15] UNI/TS 11300-1. Prestazioni energetiche degli edifici – Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale (in Italian); 2014.
[16] Directive 20120/30/EU on the indication by labeling and standard product information of the consumption of energy and other resources by energy-related products.
[17] ENEA. L'etichetta energetica; 2013. http://www.enea.it/it/pubblicazioni/pdf-opuscoli/OpuscoloEtichettaEnergetica.pdf.
[18] Costanzo V, Evola G, Gagliano A, Marletta L, Nocera F. Study on the application of cool paintings for the passive cooling of existing buildings in Mediterranean climates. Advances in Mechanical Engineering 2013;5:413675.
[19] Costanzo V, Evola G, Marletta L. Cool roofs for passive cooling: performance in different climates and for different insulation levels. Adv Build Energ Res 2013;7(2):155-169.